# Into the Eye of the Storm: Airborne Investigations of Hurricanes

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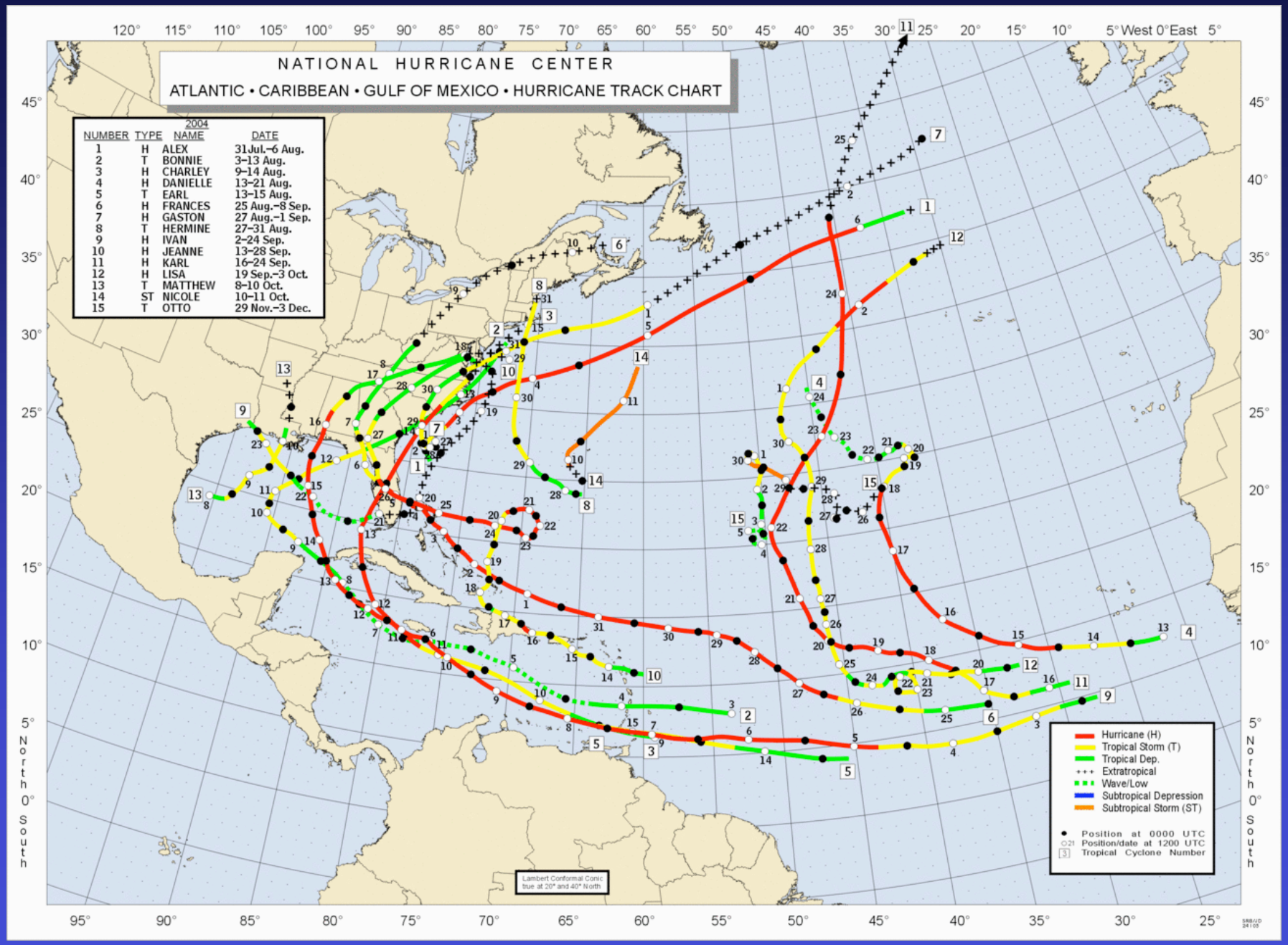
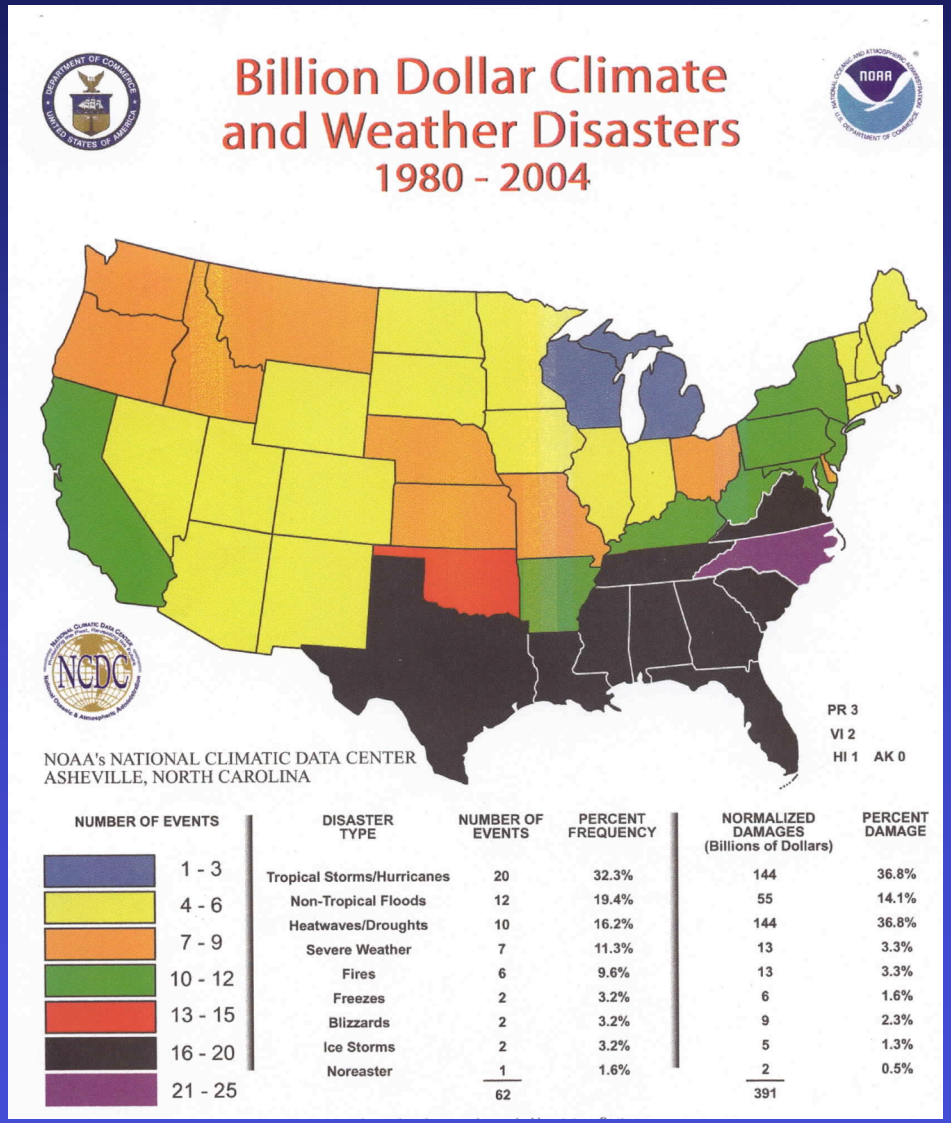
# Talk Outline

- Why study hurricanes?
- How are research flights conducted inside the storm?
- The ER-2 High Altitude Dropsonde (EHAD): A new tool to investigate the inner core of Hurricane Erin (2001)

# Why We Need To Study Hurricanes


NATIONAL HURRICANE CENTER
ATLANTIC • CARIBBEAN • GULF OF MEXICO • HURRICANE TRACK CHART
2004
NUMBER TYPE NAME DATE
1 H ALEX 31Jul.–6 Aug.
2 T BONNIE 3–13 Aug.
3 H CHARLEY 9–14 Aug.
4 H DANIELLE 13–21 Aug.
5 T EARL 13–15 Aug.
6 H FRANCES 25 Aug.–8 Sep.
7 H GASTON 27 Aug.–1 Sep.
8 T HERMINE 27–31 Aug.
9 H IVAN 2–24 Sep.
10 H JEANNE 13–28 Sep.
11 H KARL 16–24 Sep.
12 H LISA 19 Sep.–3 Oct.
13 T MATTHEW 8–10 Oct.
14 ST NICOLE 10–11 Oct.
15 T OTTO 29 Nov.–3 Dec.
Hurricane (H)
Tropical Storm (T)
Tropical Dep.
Extratropical
Wave/Low
Subtropical Depression
Subtropical Storm (ST)
Position at 0000 UTC
Position/date at 1200 UTC
Tropical Cyclone Number
Lambert Conformal Conic
true at 20° and 40° North

# Why We Need To Study Hurricanes




| DISASTER TYPE | NUMBER OF EVENTS | PERCENT FREQUENCY | NORMALIZED DAMAGES (Billions of Dollars) | PERCENT DAMAGE |
|---|---|---|---|---|
| Tropical Storms/Hurricanes | 20 | 32.3% | 144 | 36.8% |
| Non-Tropical Floods | 12 | 19.4% | 55 | 14.1% |
| Heatwaves/Droughts | 10 | 16.2% | 144 | 36.8% |
| Severe Weather | 7 | 11.3% | 13 | 3.3% |
| Fires | 6 | 9.6% | 13 | 3.3% |
| Freezes | 2 | 3.2% | 6 | 1.6% |
| Blizzards | 2 | 3.2% | 9 | 2.3% |
| Ice Storms | 2 | 3.2% | 5 | 1.3% |
| Noreaster | 1 | 1.6% | 2 | 0.5% |
| | 62 | | 391 | |

**1992: Andrew $35 billion**

**2004:**

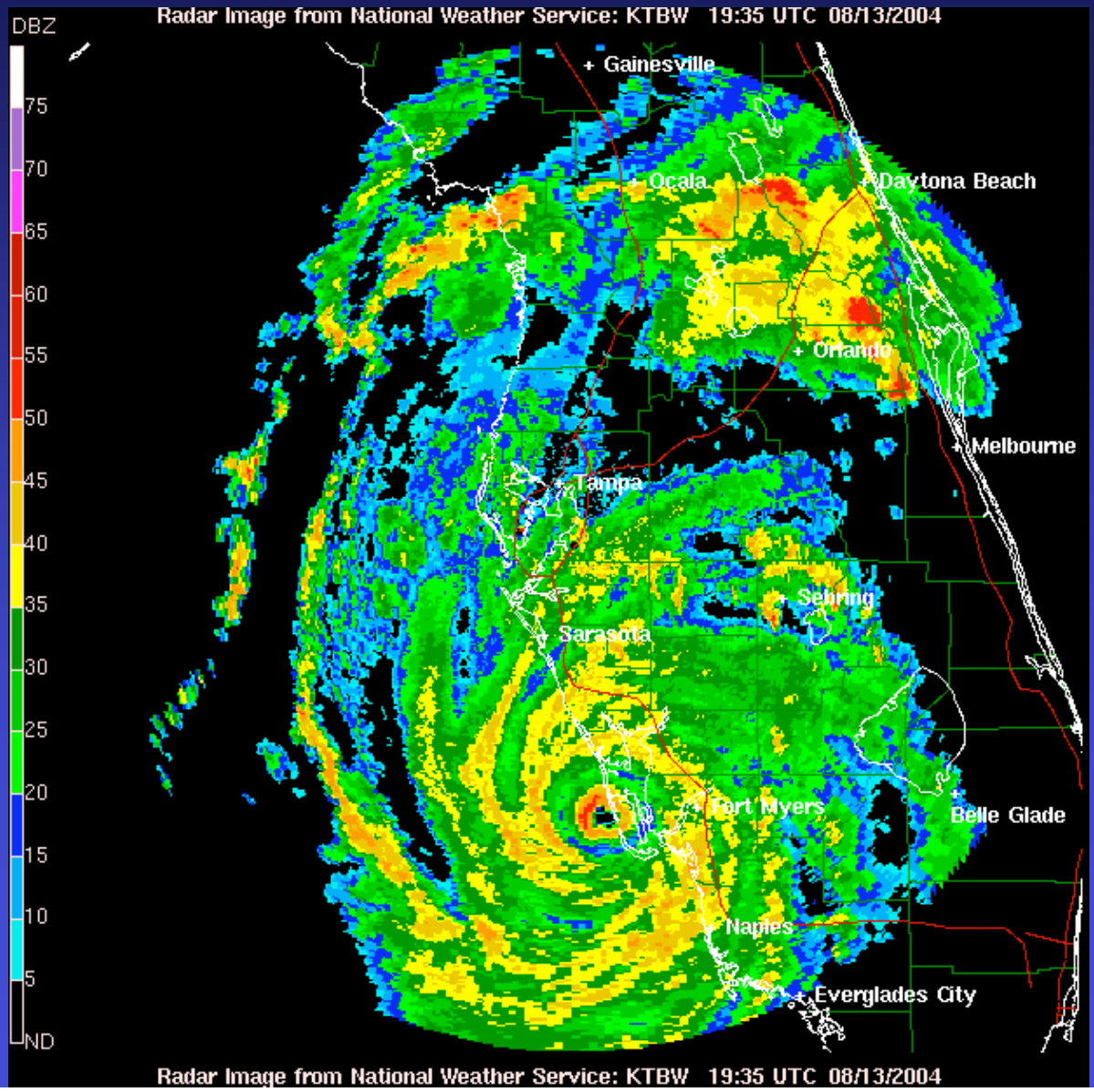
**Charley $14 billion**
**Frances $ 9 billion**
**Ivan $12 billion**
**Jeanne $ 7 billion**

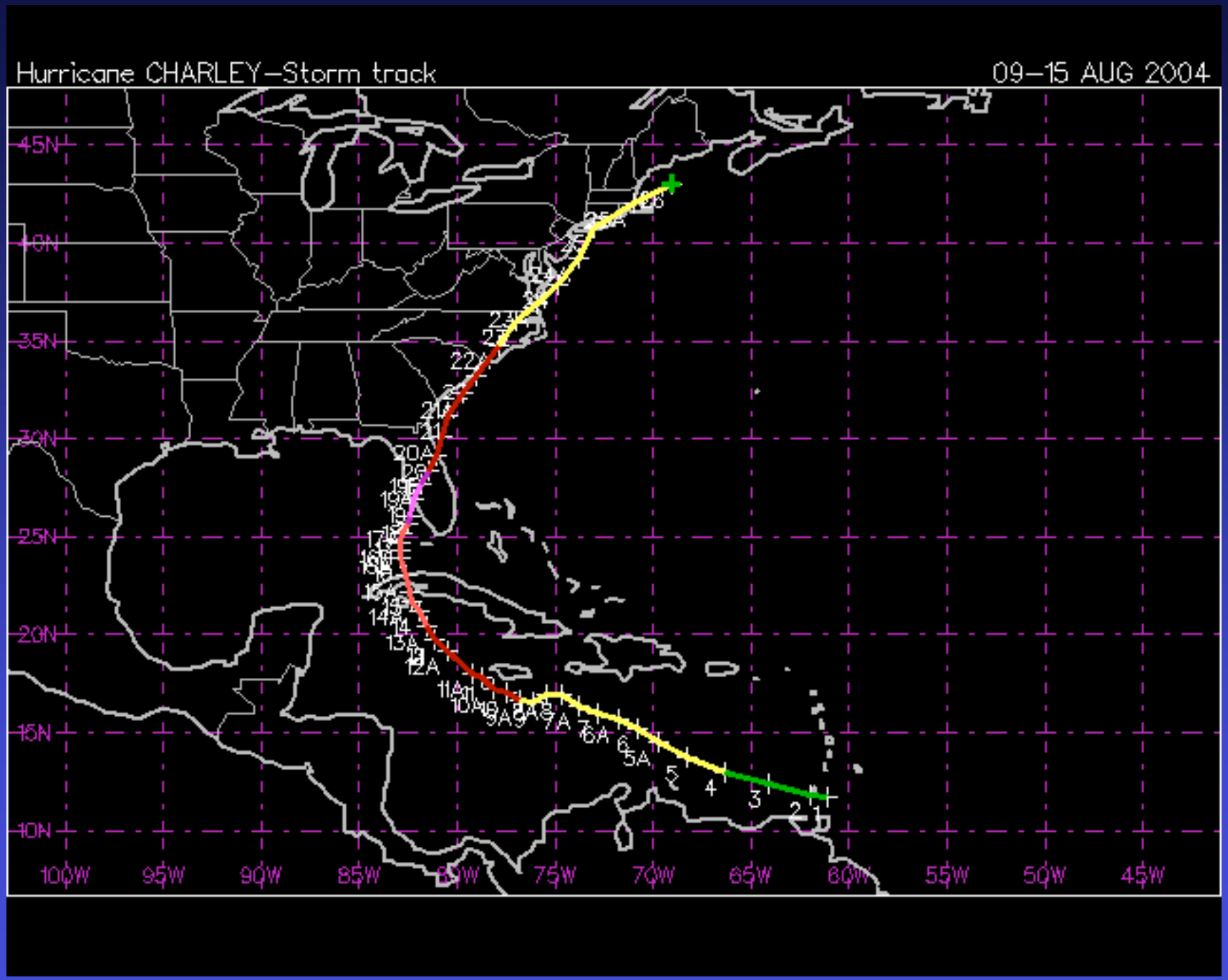
*$ 42 billion*

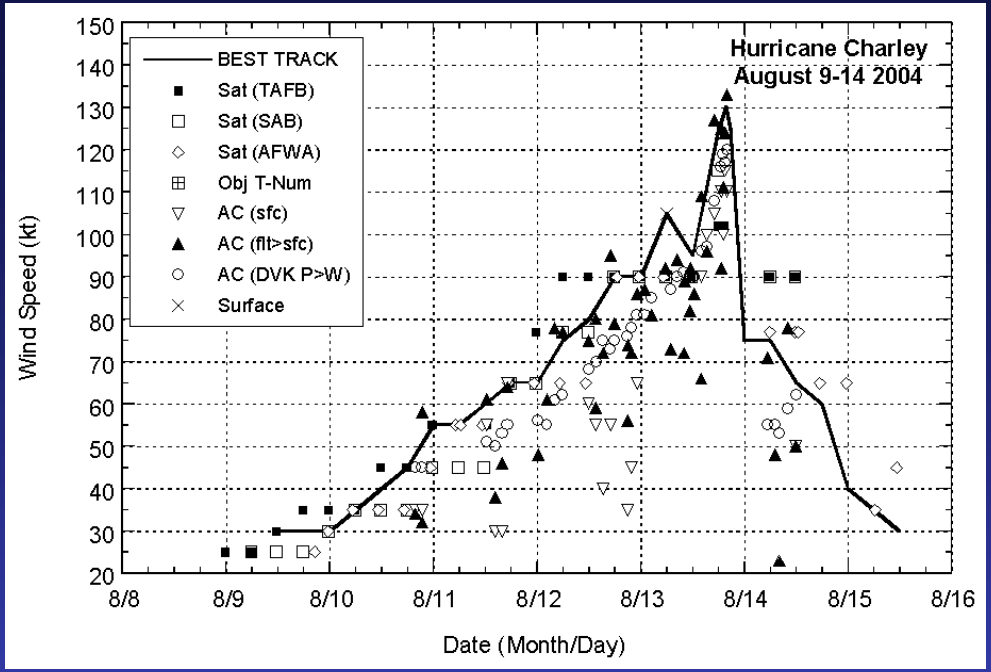
***Since 1980: $150 billion***

*normalized to 2002 dollars

# 2004 Bad Actor:  Hurricane Charley




Hurricane CHARLEY–Storm track
09–15 AUG 2004
45N
40N
35N
30N
25N
20N
15N
10N
100W
95W
90W
85W
80W
75W
70W
65W
60W
55W
50W
45W

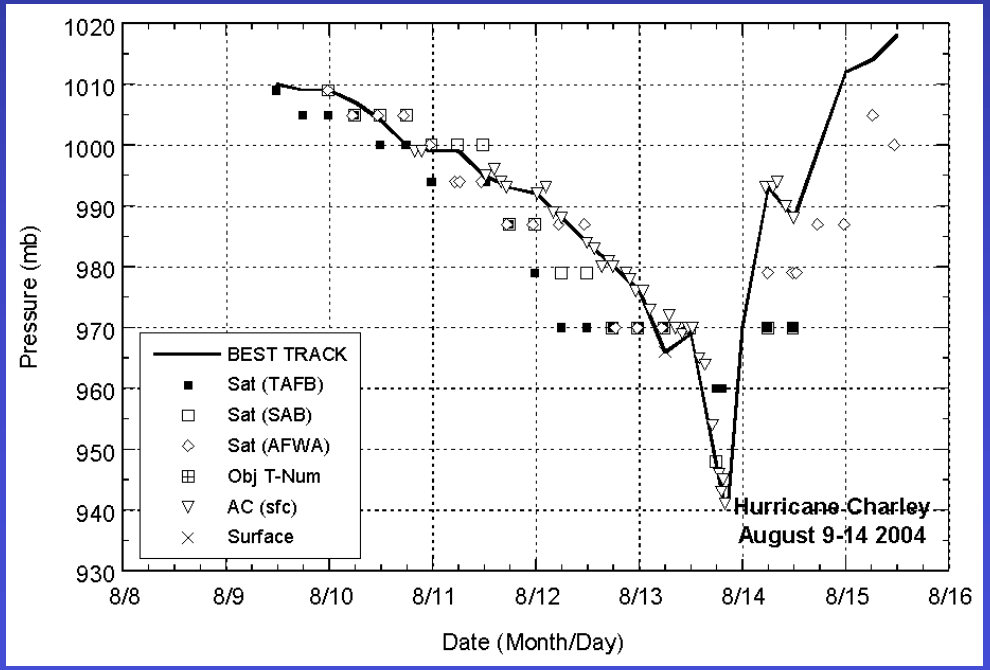



# Explosive Intensification Of Charley - *Hours* Before Landfall - Forecaster's Nightmare

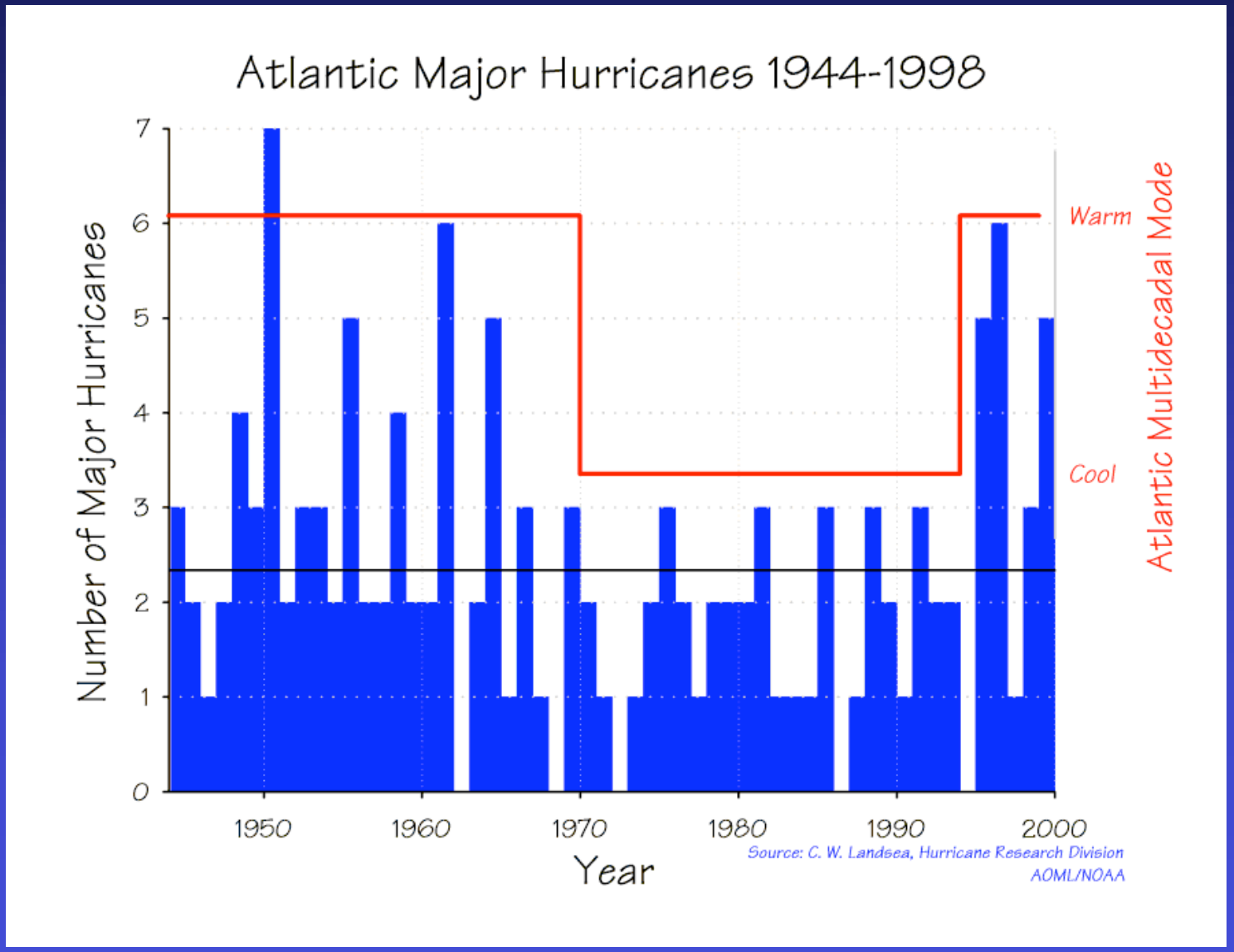
**Over the past three decades, forecasts of hurricane track have improved by 25-30%.**

***There has been little improvement in our ability to forecast hurricane intensity change.***

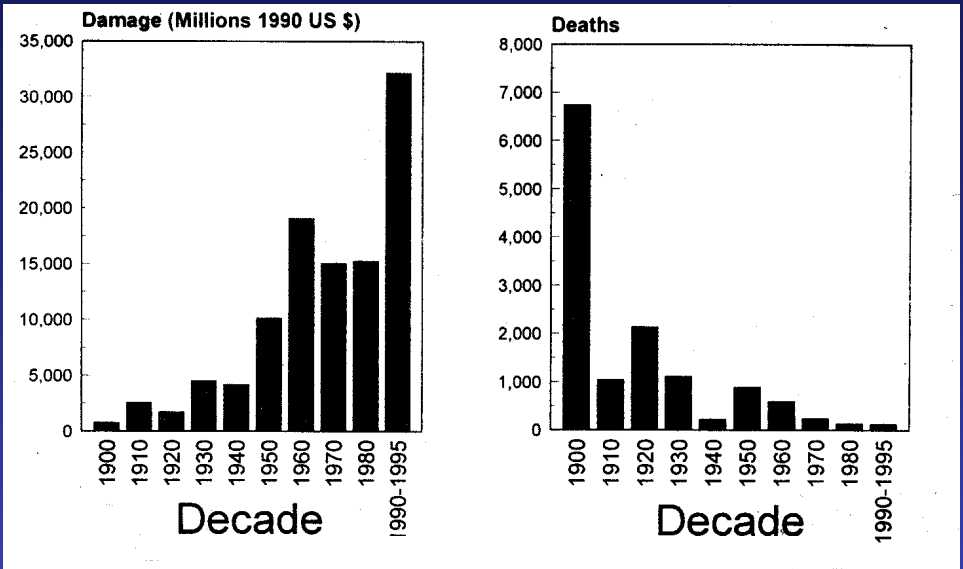
**This is where NASA's research efforts are focused.**



# Outlook for Atlantic Hurricane Activity



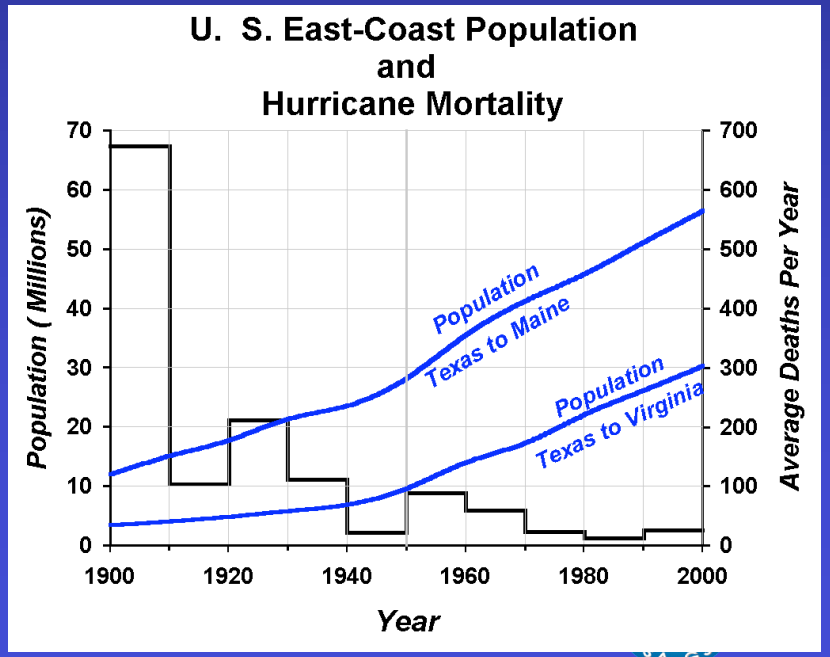
# U.S. Hurricane Death and Damage Trends




**Hurricane deaths & damage trends are inversely related**

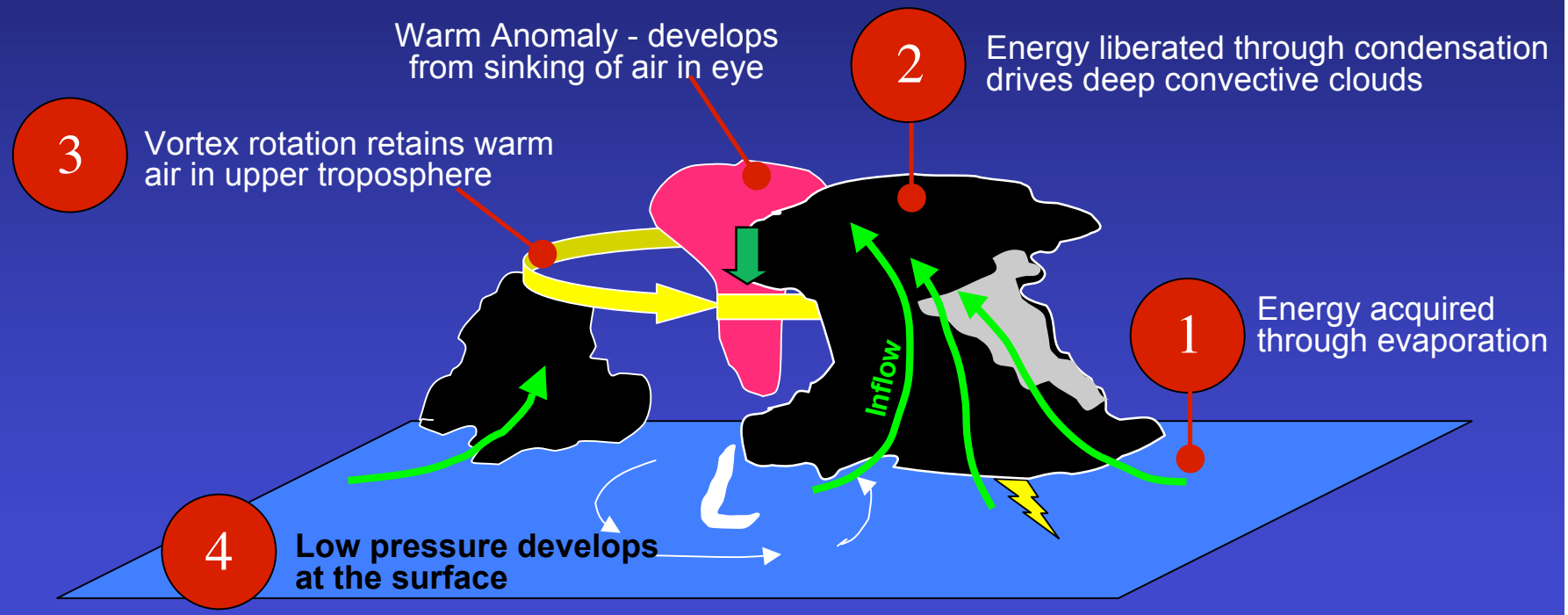
**Population & property along the U.S East Coast is growing exponentially (RISK)**

***Hurricane Vulnerabilty = Hazard x Risk***



# Hurricane Heat Engine for (Intelligent) Dummies

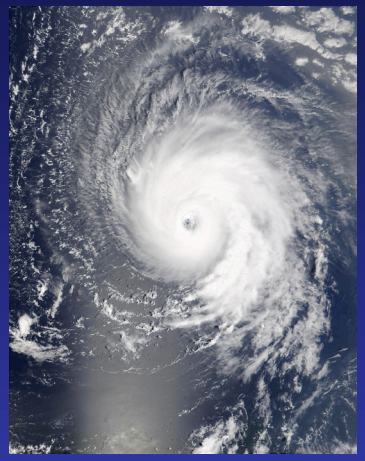
***The sea provides the energy…the atmosphere provides the rotation***




- *Warming and sea level pressure are related through hydrostatic balance*

# NASA Hurricane Science: Three Prongs

1. Satellite Remote Sensors

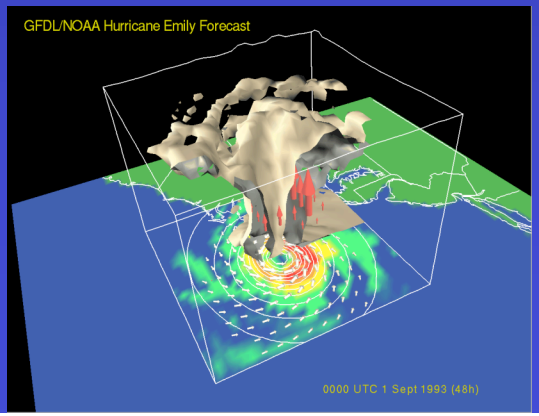


2. Field Campaigns to Investigate Hurricanes

NASA ER-2

NASA DC-8

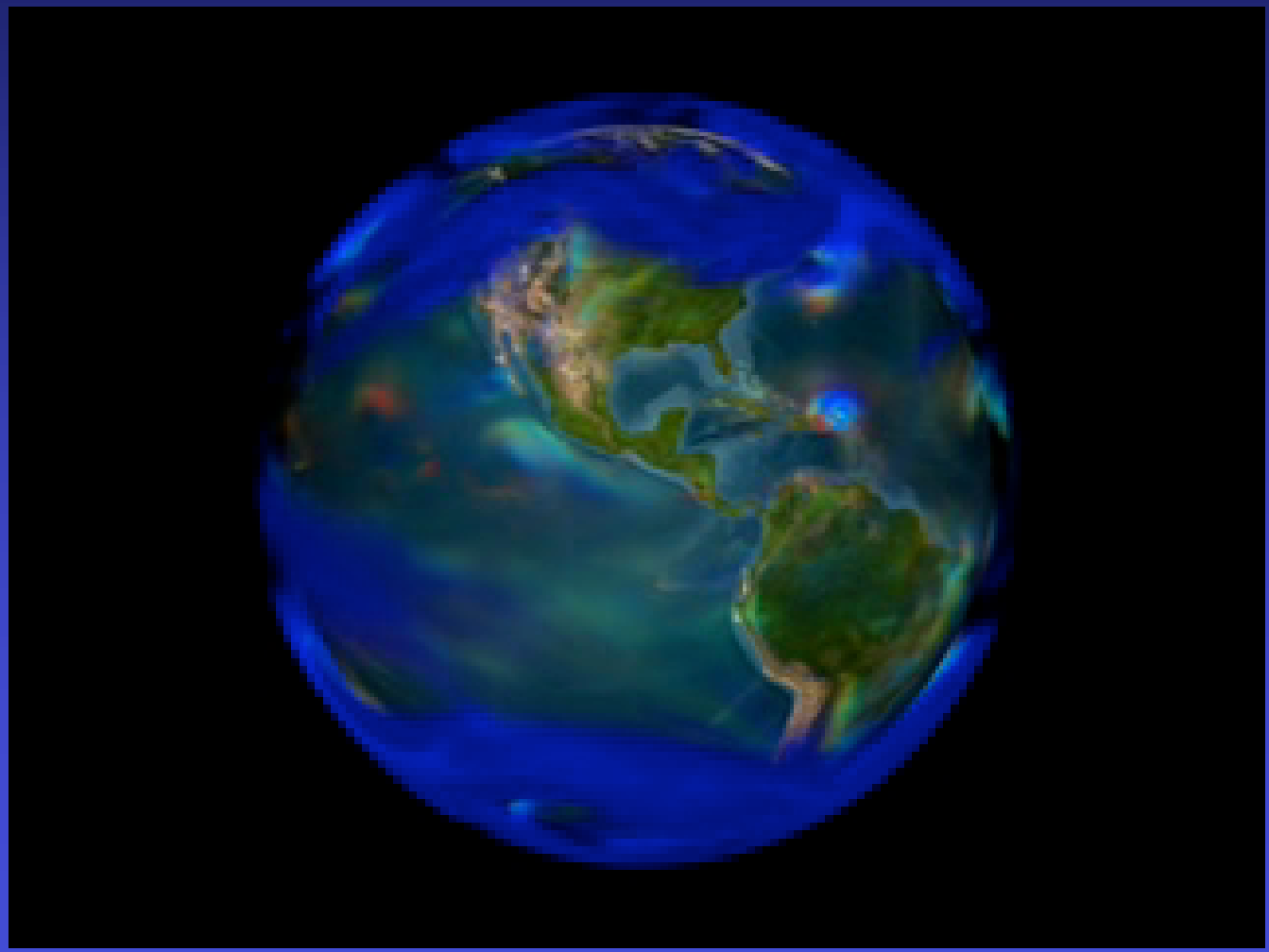
3. Numerical Models



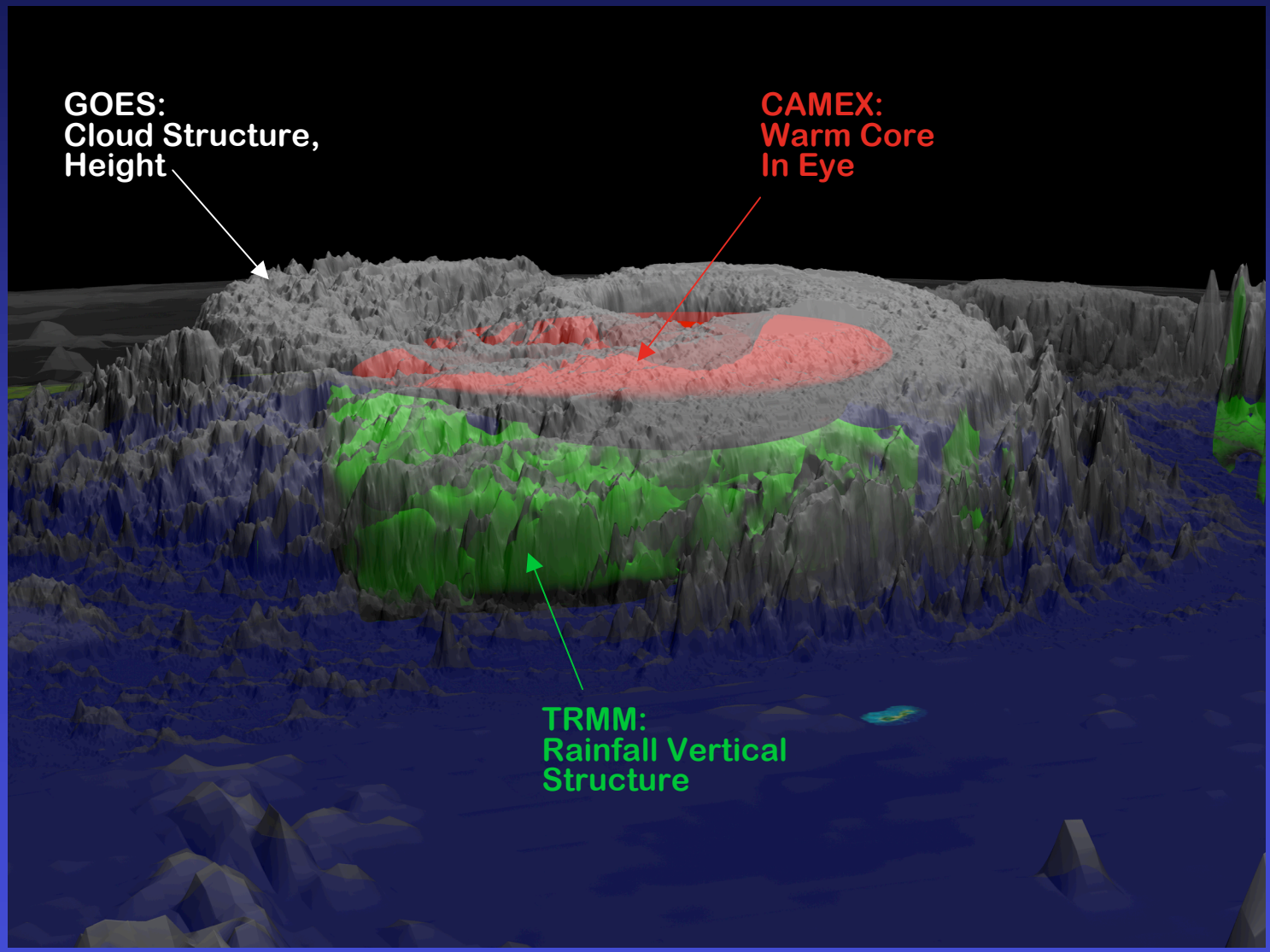

# Satellite Remote Sensors: Hurricane CAT Scan

# NASA High Altitude Research Aircraft

# NASA fvGCM Global Hurricane Simulations

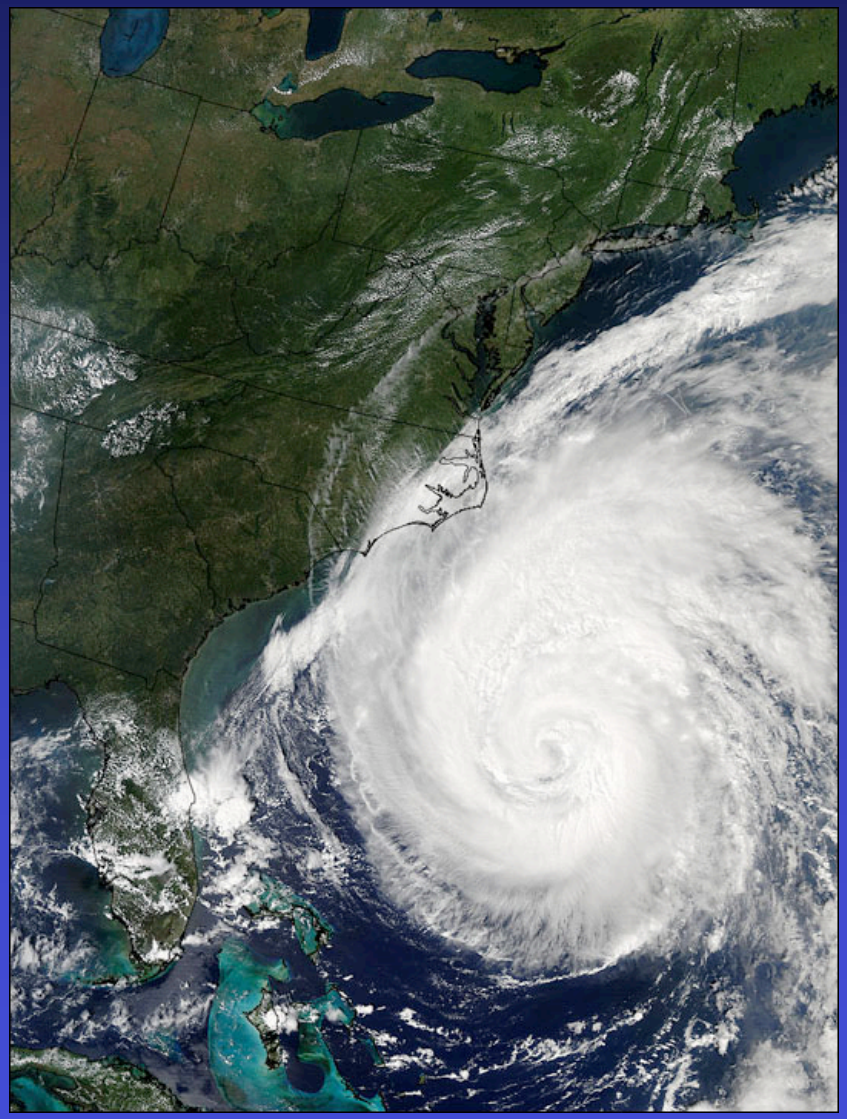


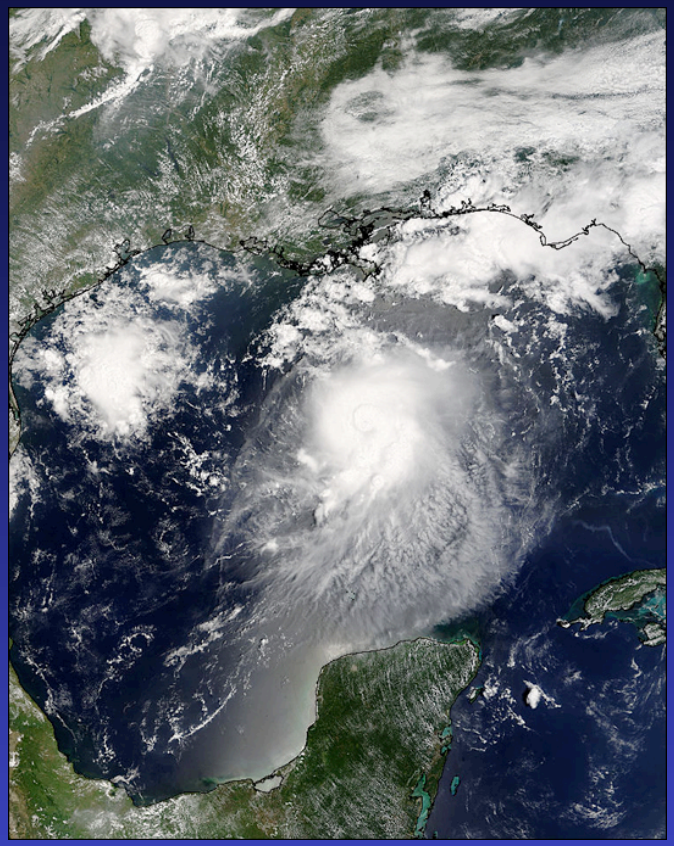
# Synergy Between Satellites & Aircraft



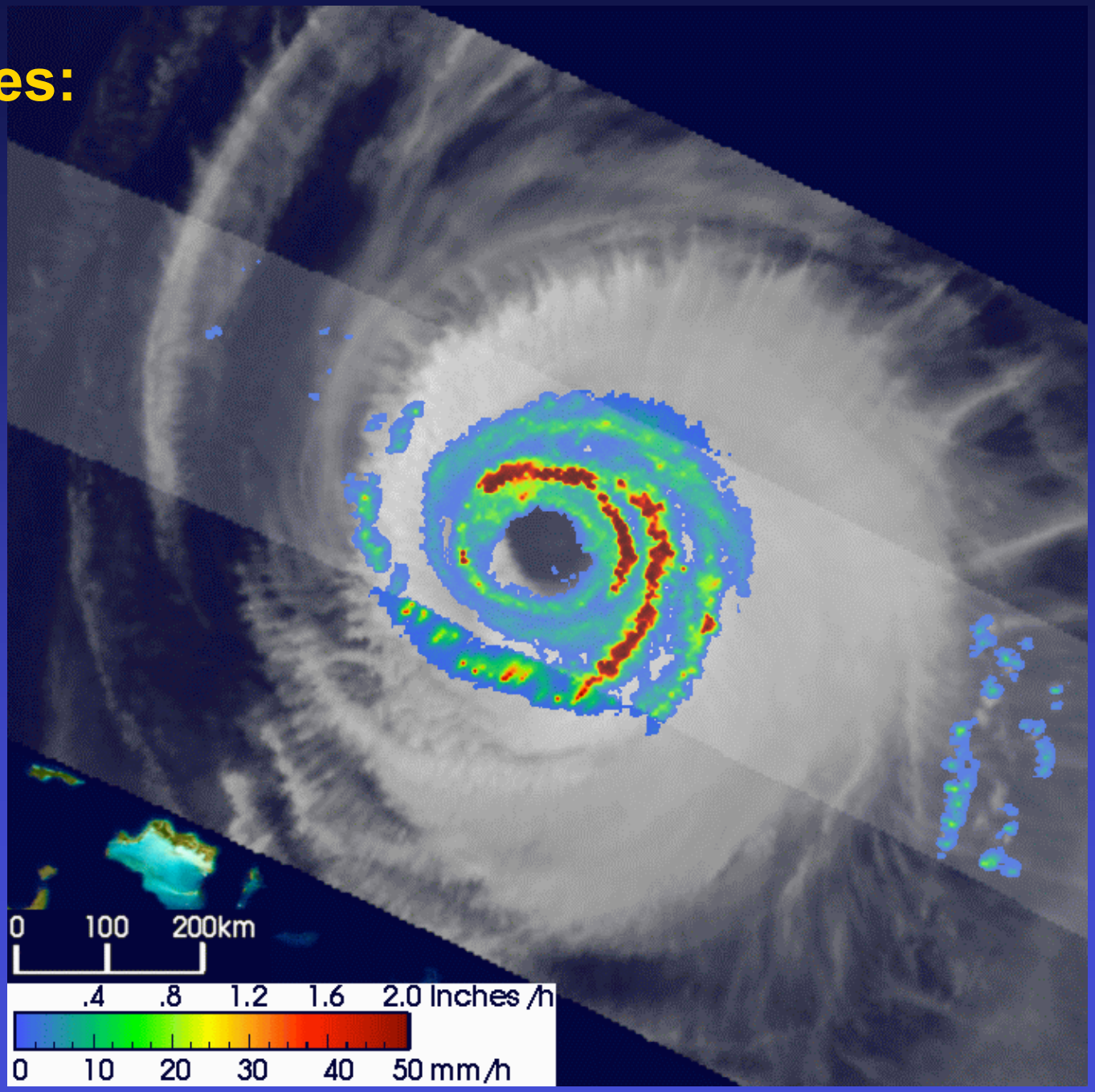
# Synergy Between Satellites & Aircraft

# NASA Satellites: MODIS

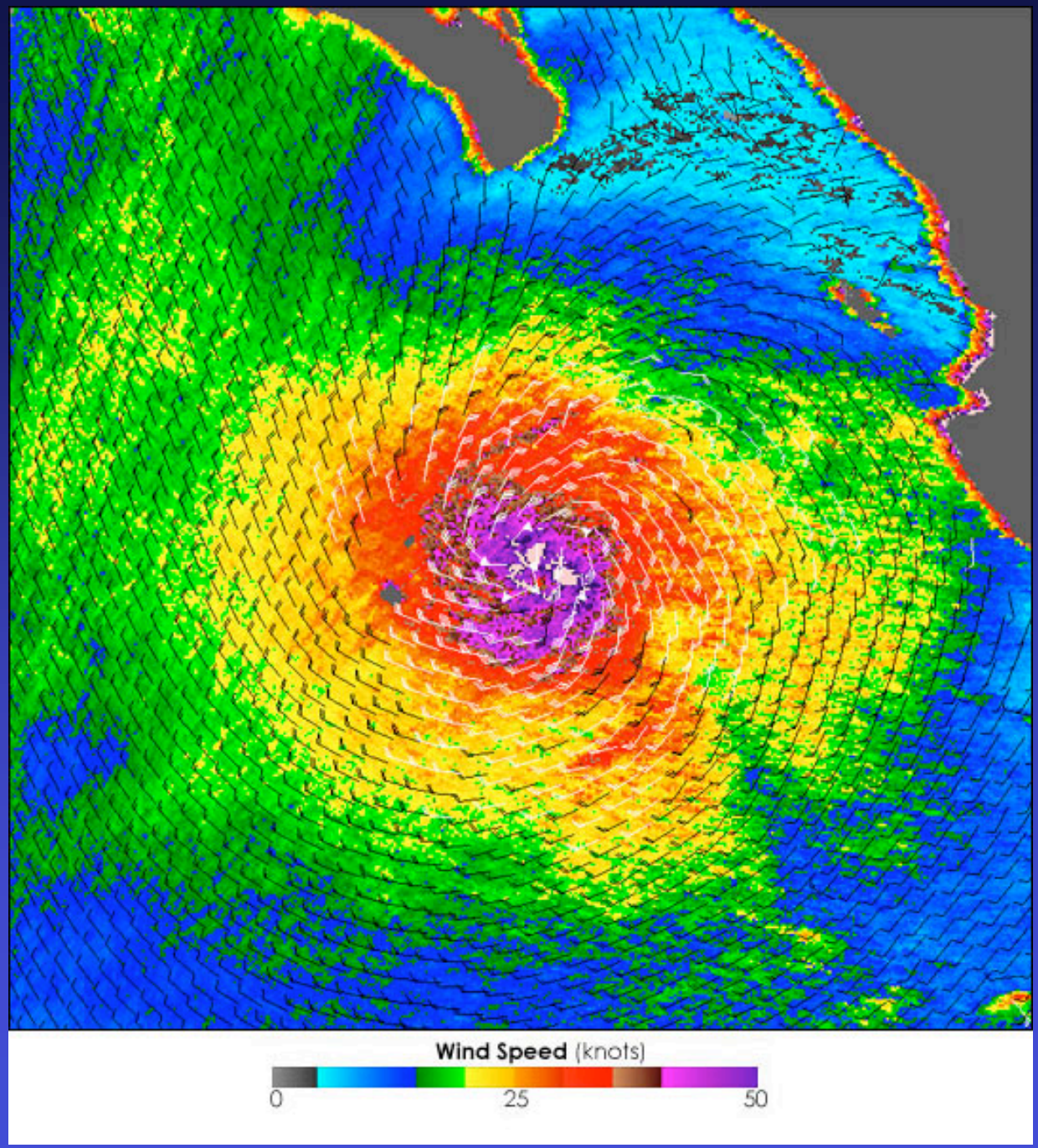




# NASA Satellites: TRMM



# NASA Satellites: QuikSCAT



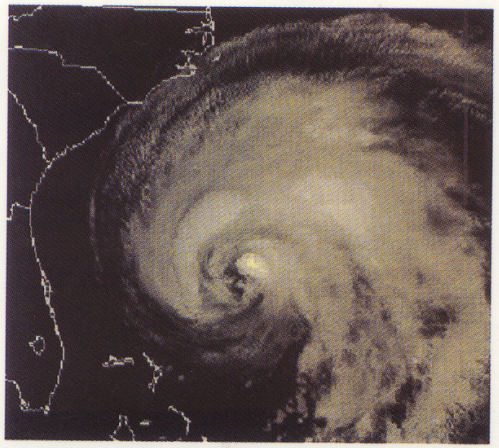
# NOAA AMSU

## Advanced Microwave Sounding Unit

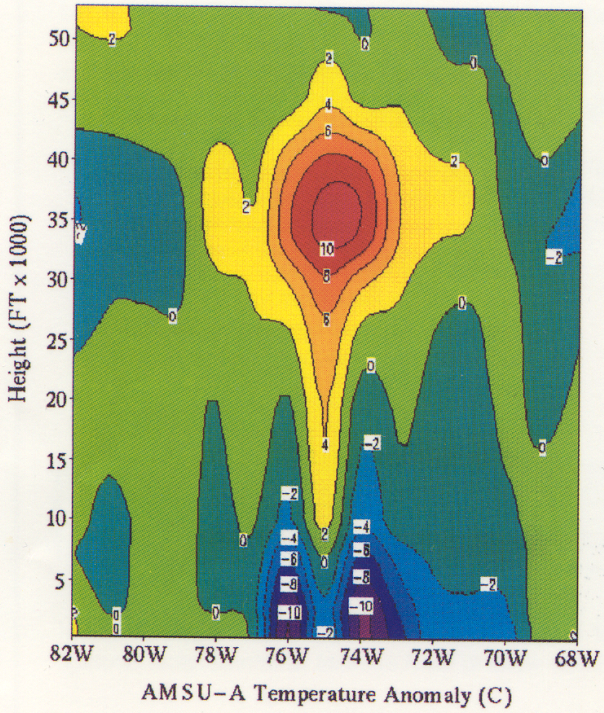
Hurricane Bonnie

25 August 1998

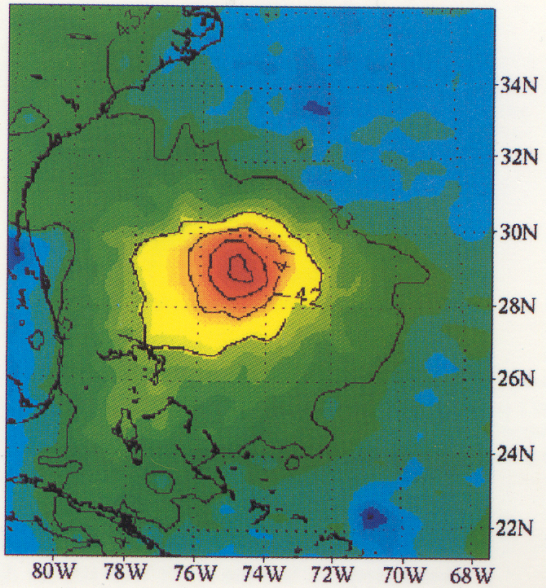
NOAA–15 Satellite



AVHRR Infrared




AMSU–A Temperature Anomaly (C)




AMSU–A Channel 7 Brightness Temperature (C)

# Hurricane Research: Aircraft Investigations

## CAMEX: Convection and Moisture Experiment (1998, 2001) in NATL, GOMEX

### NASA & NOAA HRD coordinated aircraft missions into hurricanes

**GOAL: Investigate the structure and dynamics of hurricanes and factors leading to their intensity change, from sea surface to above cloud tops.**




# NASA DC-8 Flying Laboratory

NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/Gallery/Photo/index.html
NASA Photo: EC04-0047-02 Date: February 24, 2004 Photo By: Jim Ro

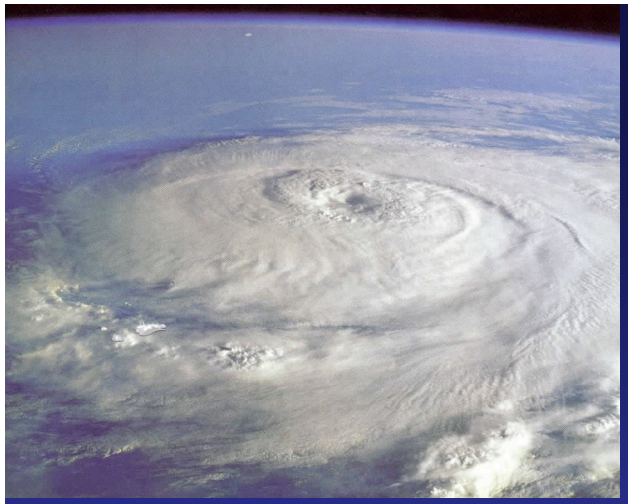
NASA's Airborne Science DC-8, displaying new colors in a check flight Feb. 24, 20
Dryden Flight Research Center.

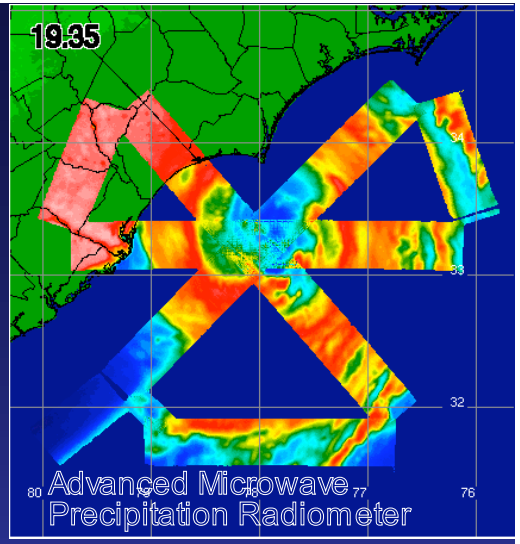
# Missions Inside The Storm


# NASA ER-2 High Altitude Aircraft


NASA Dryden flight Research Center Photo Collection
http://www.dfrc.nasa.gov/gallery/photo/index.html
NASA Photo: EC01-0232-2 Date: August 1, 2001

Lockheed ER-2 #809 high altitude research aircraft in flight

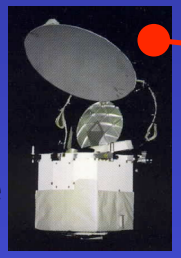


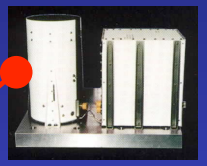



# NASA ER-2:
# *Virtual Satellite*

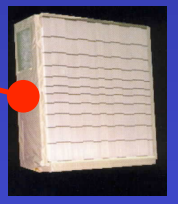
MODIS

TRMM
Microwave
Imager



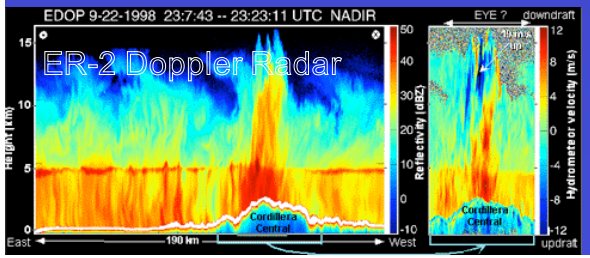


Lightning
Imaging Sensor



Precipitation
Radar

AMSR-E




# CAMEX Scientific Missions

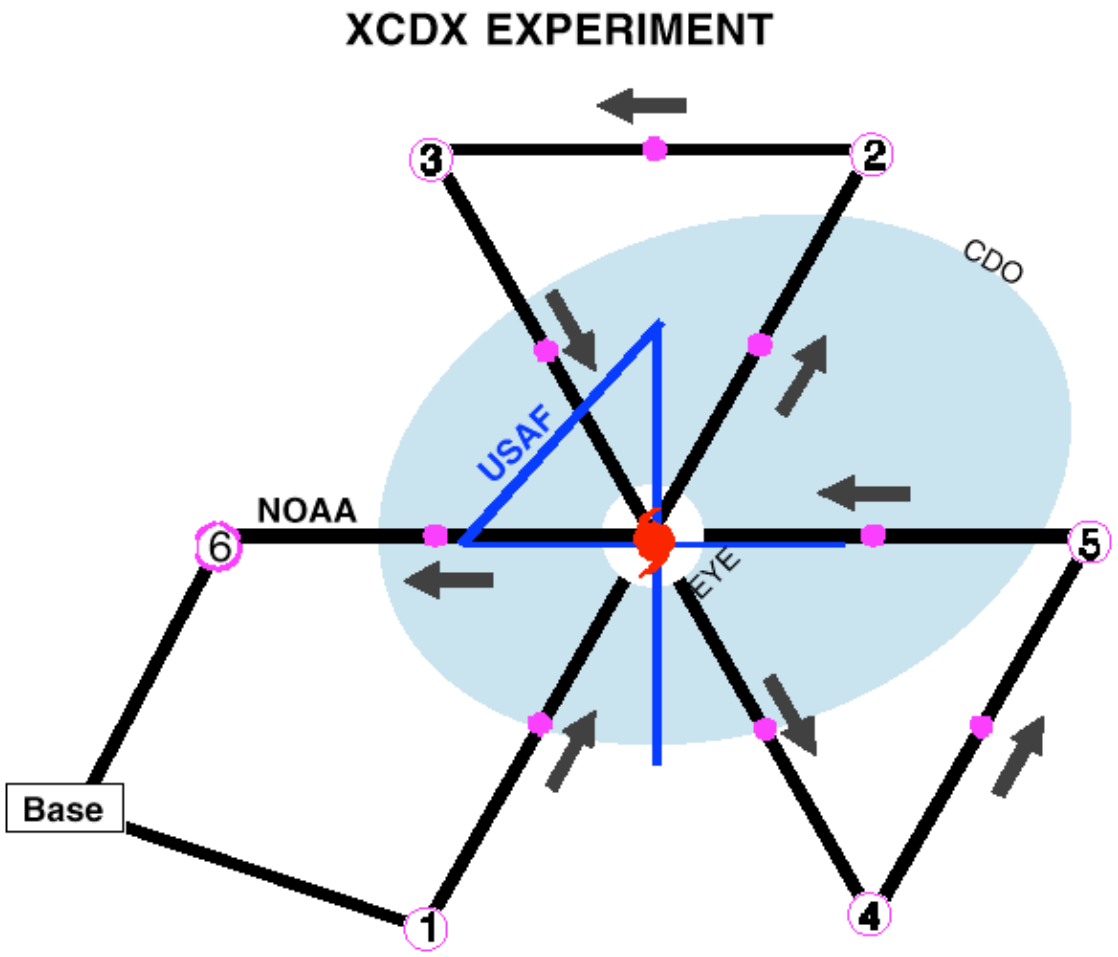



Fig. 3. WP-3D pattern

Strategy: Multiple aircraft fly intersecting flight legs across the storm at center at different altitudes (5,000' up to 70,000') - "vertical stack".

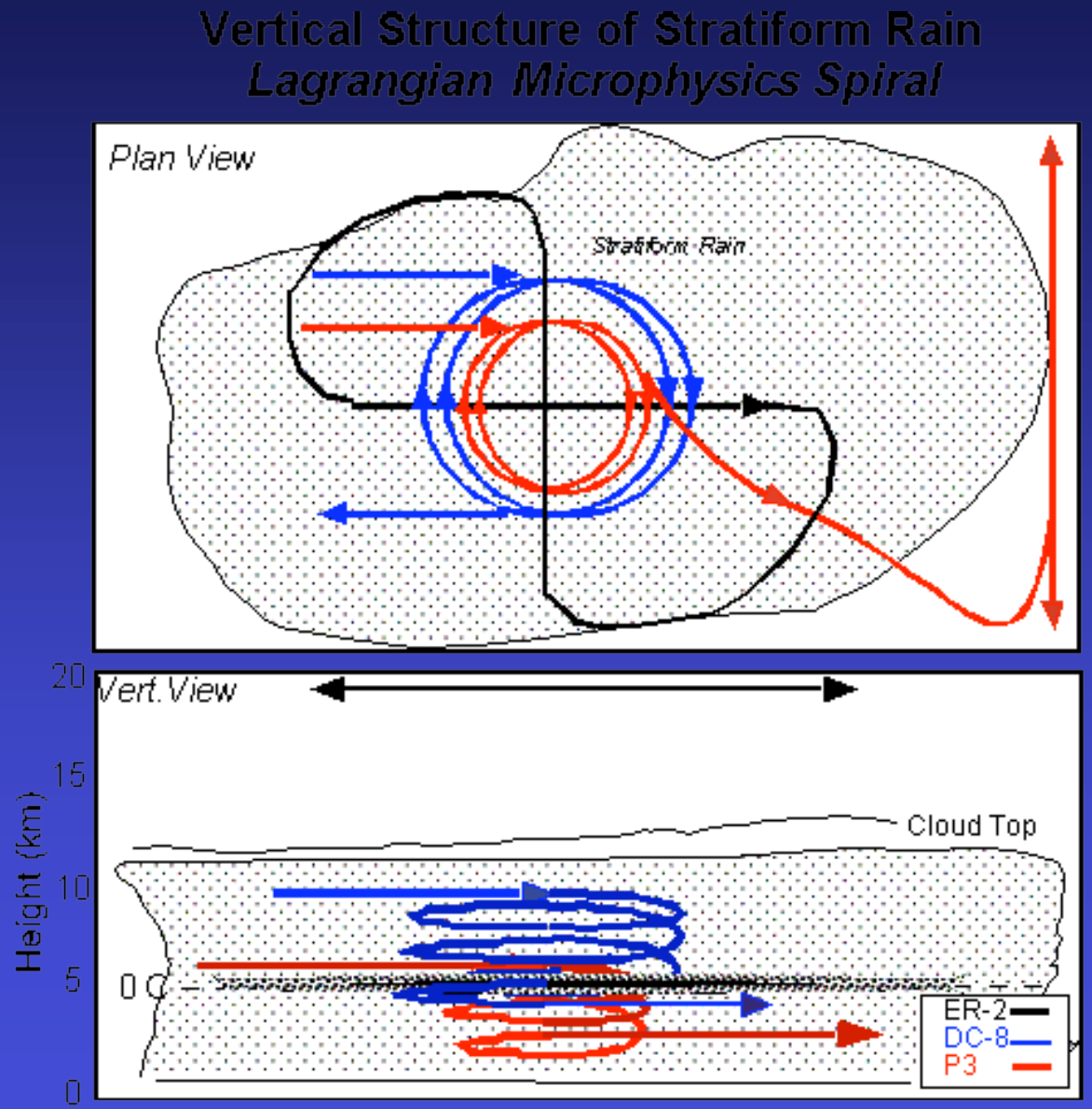
All aircraft are coordinated according to the radar pattern of precipitation structure and intensity.

Dropsondes are released at multiple, regularly spaced points.

Special instrumentation on aircraft include lasers to determine water vapor concentration, cloud particle probes to sample ice and liquid hydrometeors, temperature profilers, flight level winds and meteorological conditions.

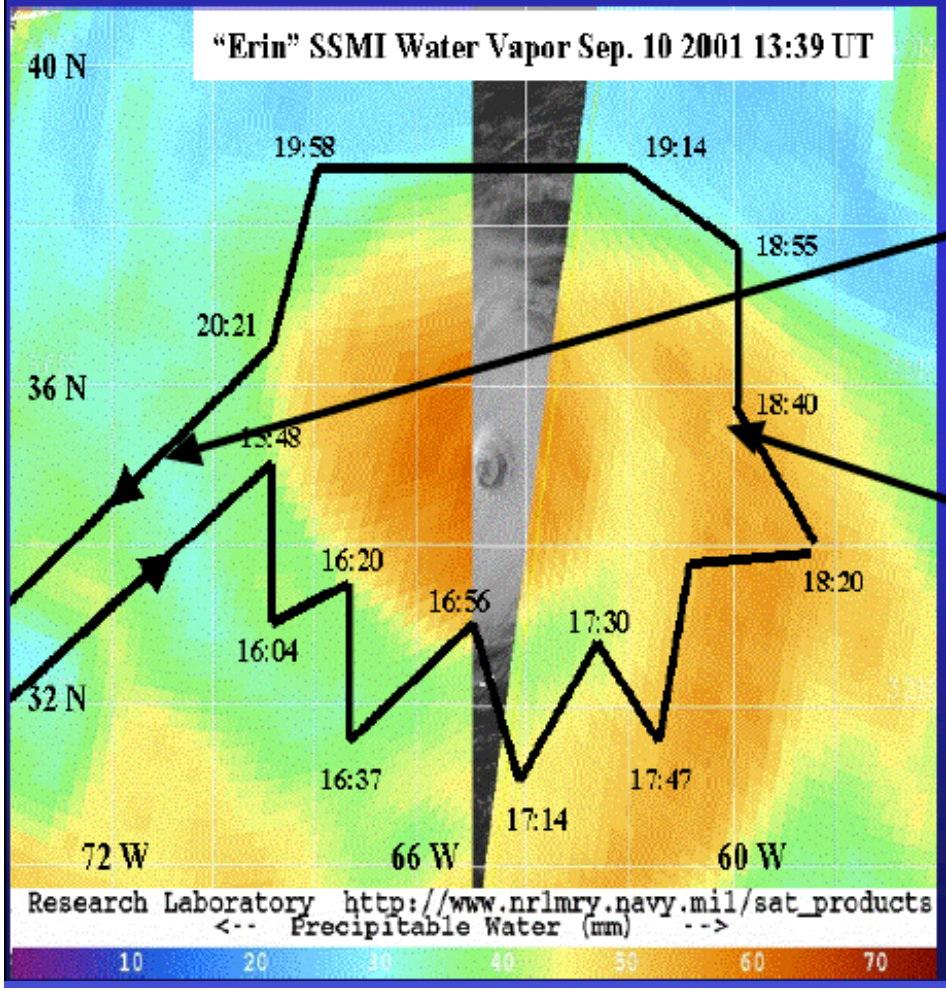
Typical mission lasts 8 hours; 10-13 missions flown during each CAMEX.

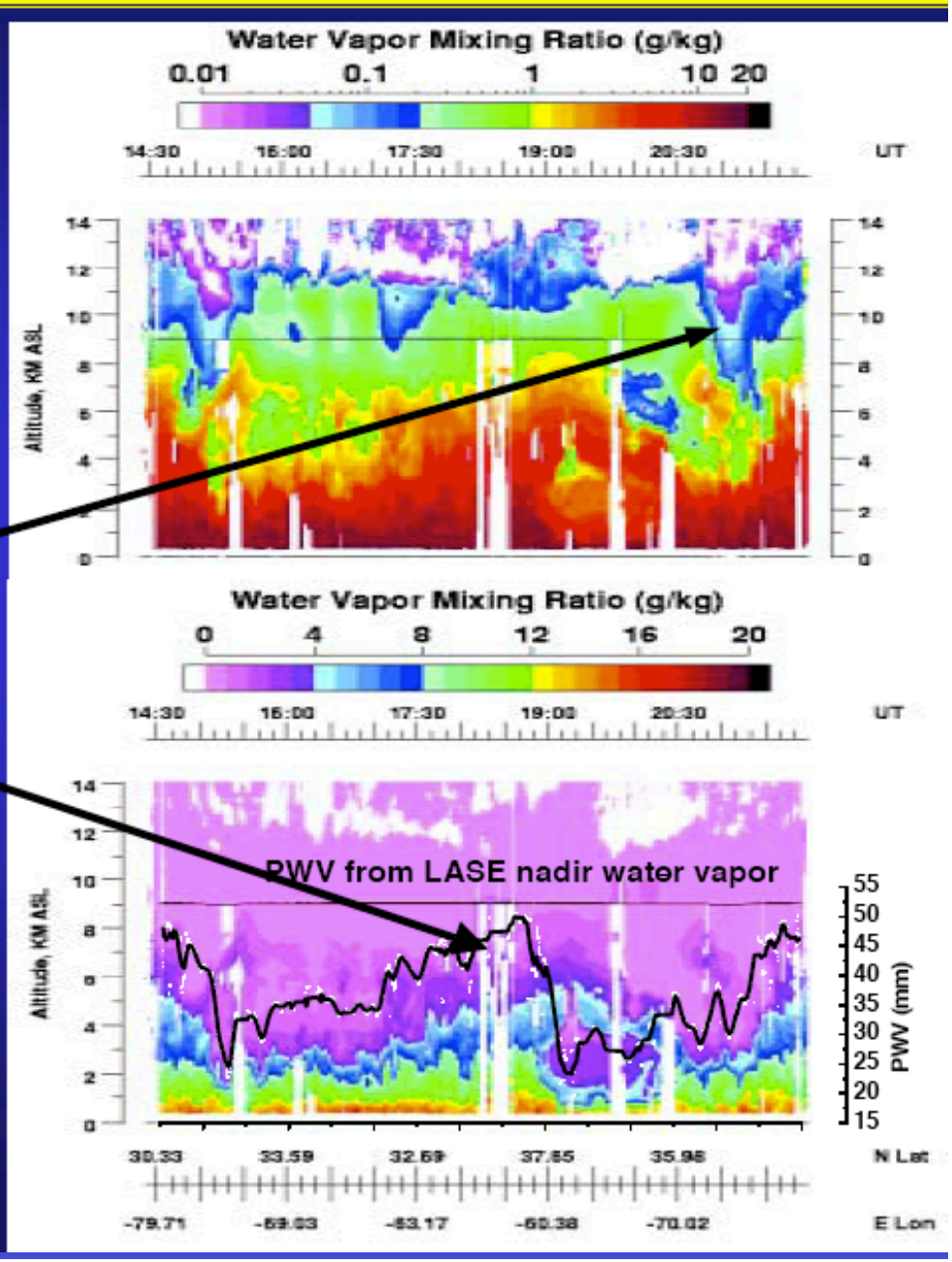
# Coordinated Aircraft Sampling



# CAMEX-4 Hurricane Erin "Optimal Data Assimilation" Flight

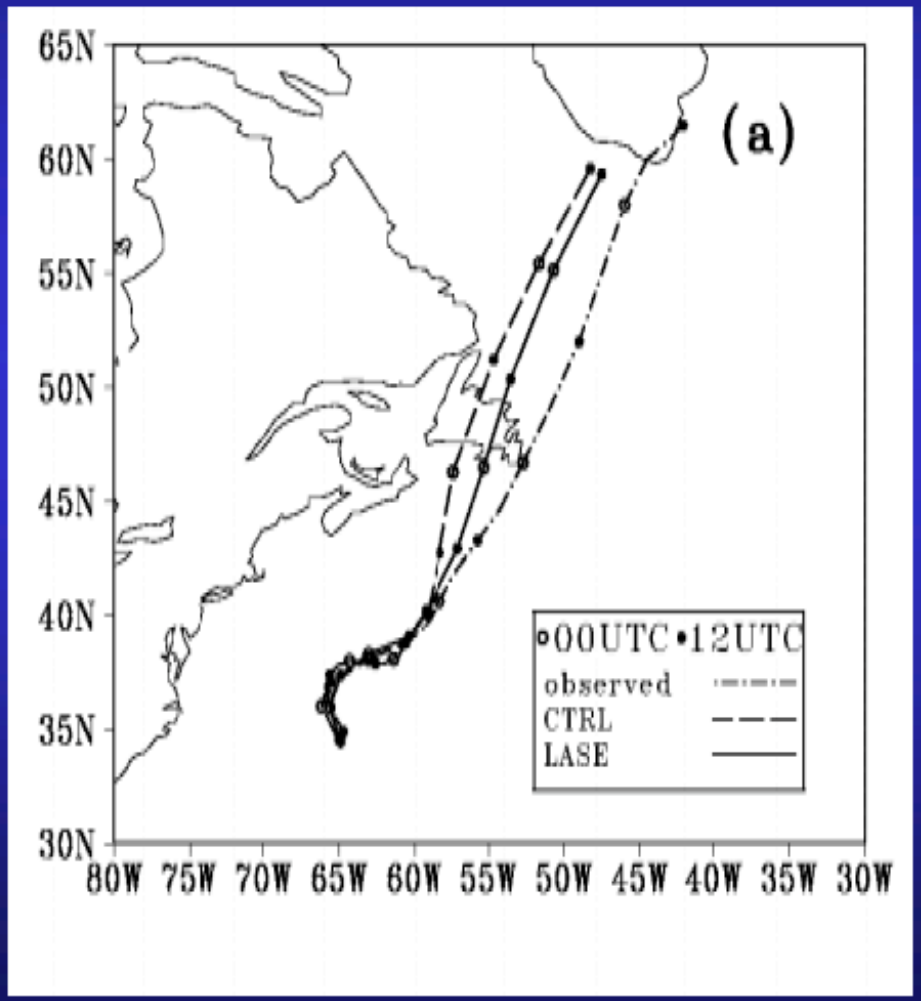
- High water vapor northeast of storm
- Mid-upper level dry region associated with cold trough southwest of storm
- Large variation in integrated water vapor



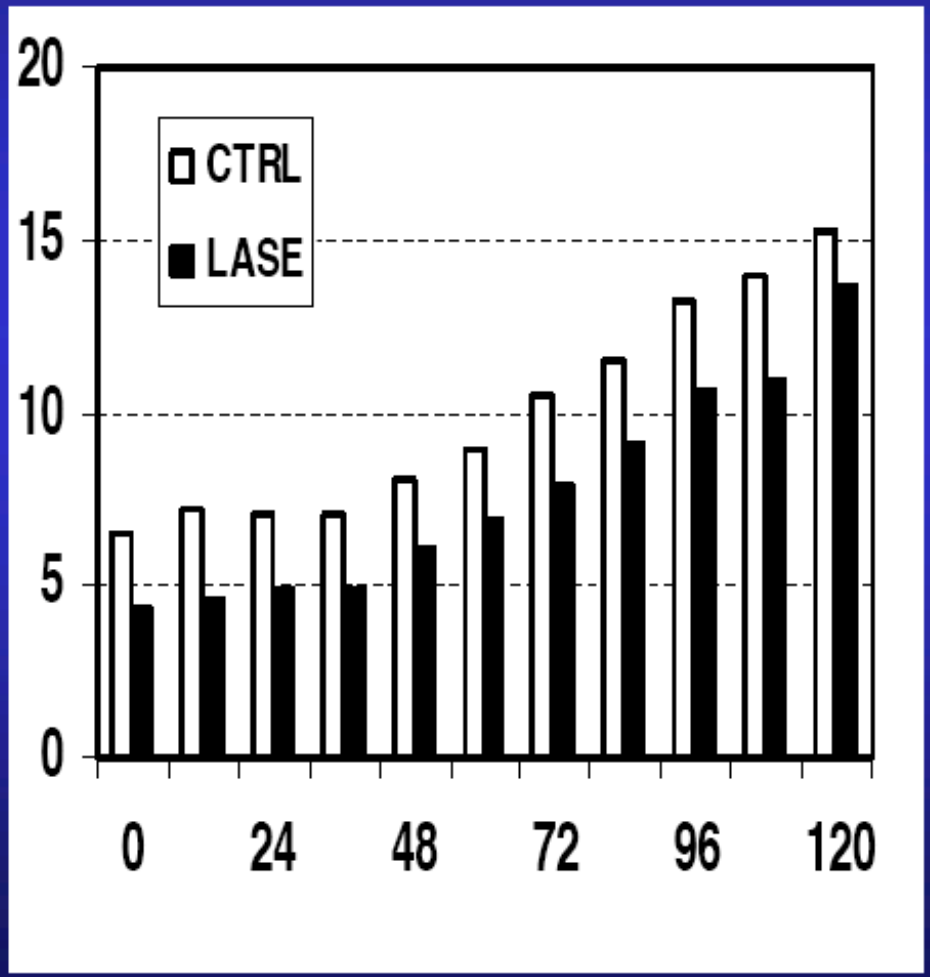



# FSU Model Results for Hurricane Erin using CAMEX-4 LASE Data

120hr forecast track of Hurricane Erin
IC: 12UTC 10 Sep 2001

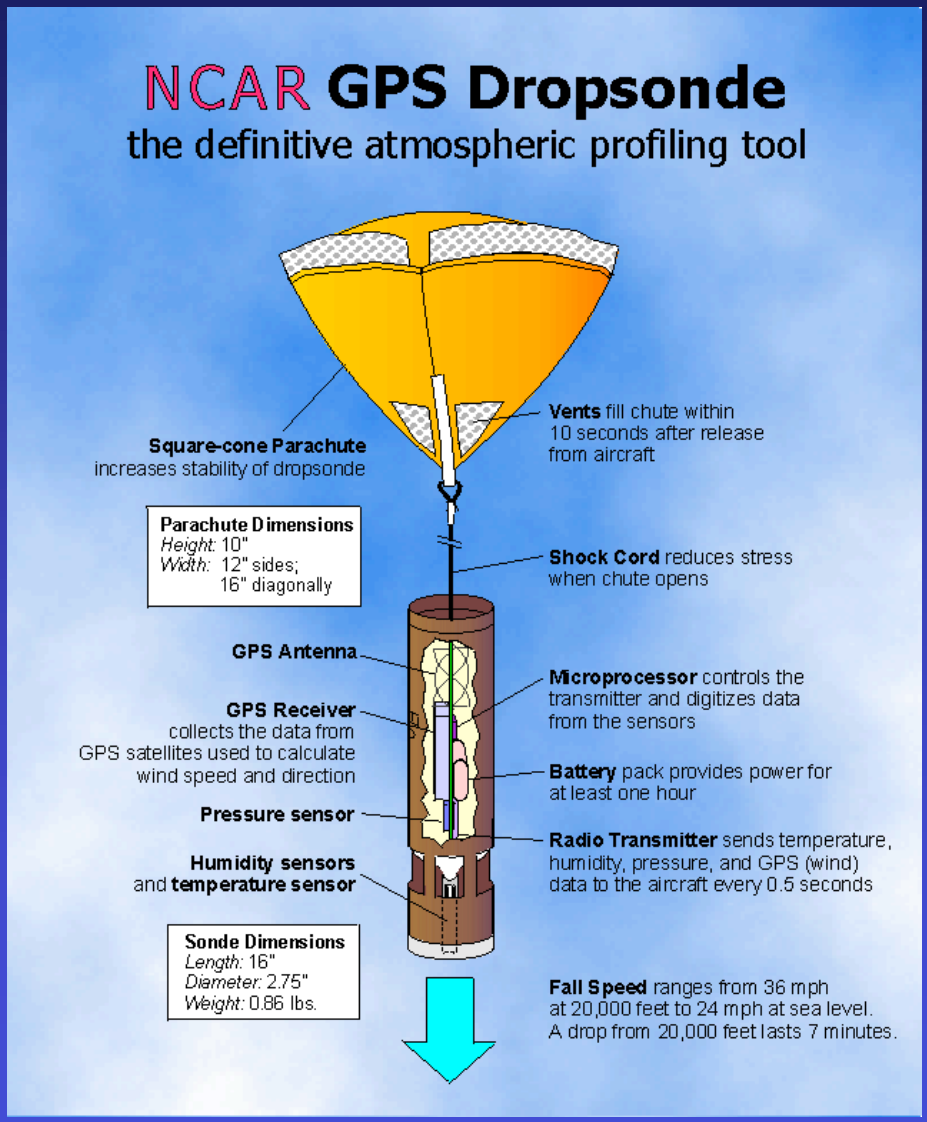


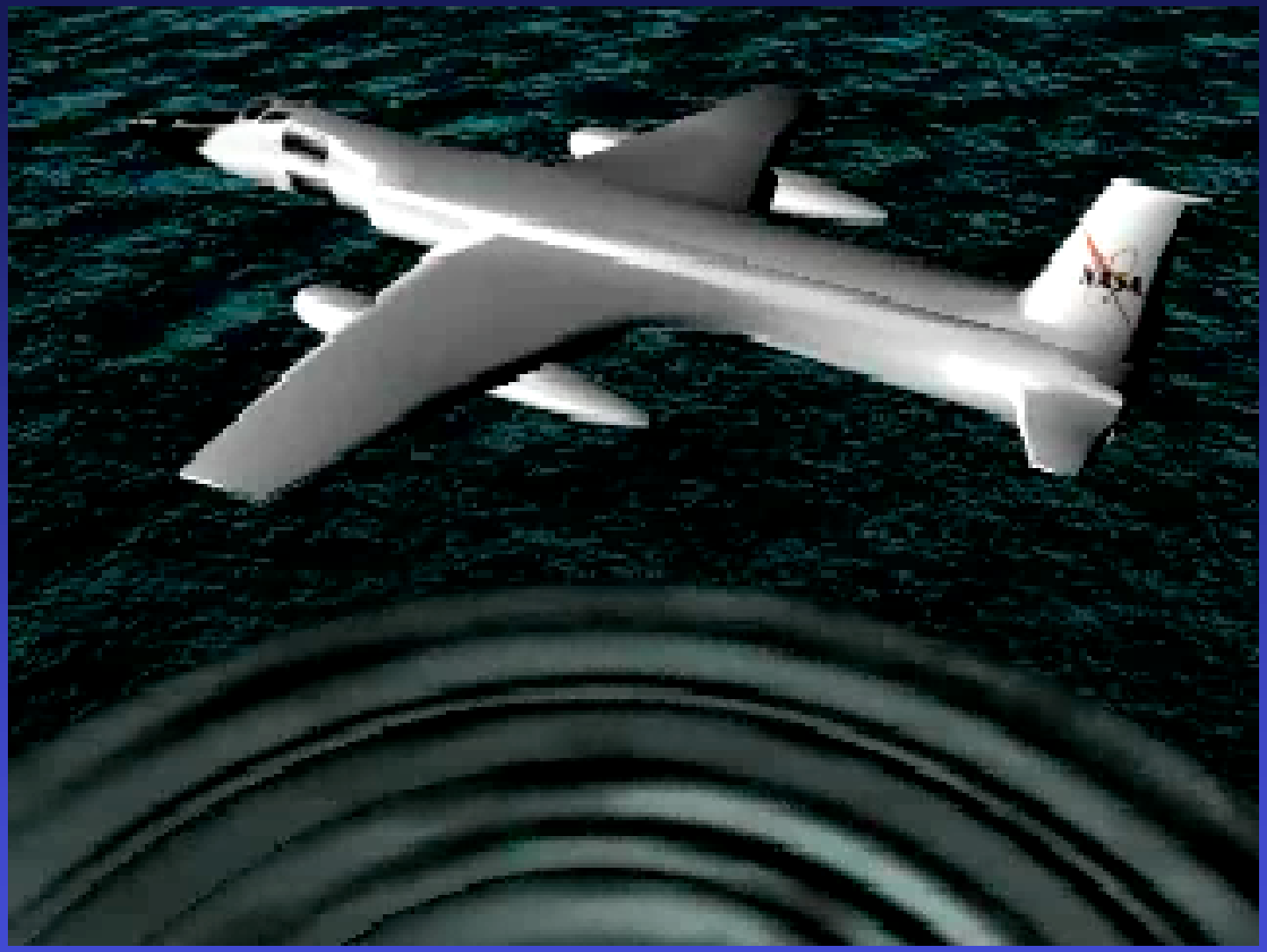

Intensity errors (in m/s) of Hurricane Erin
IC: 12UTC 10Sep 2001



# DC-8 Dropsonde

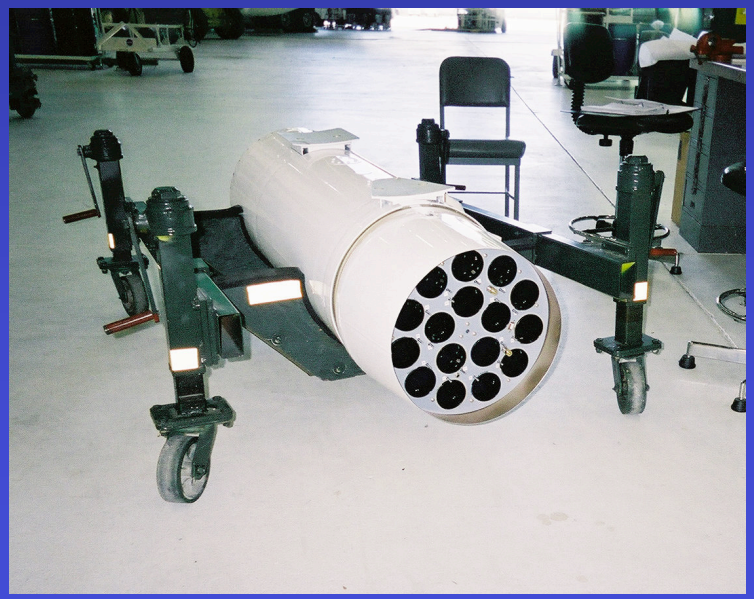
## Vertical Temperature, Moisture, Wind Profiles

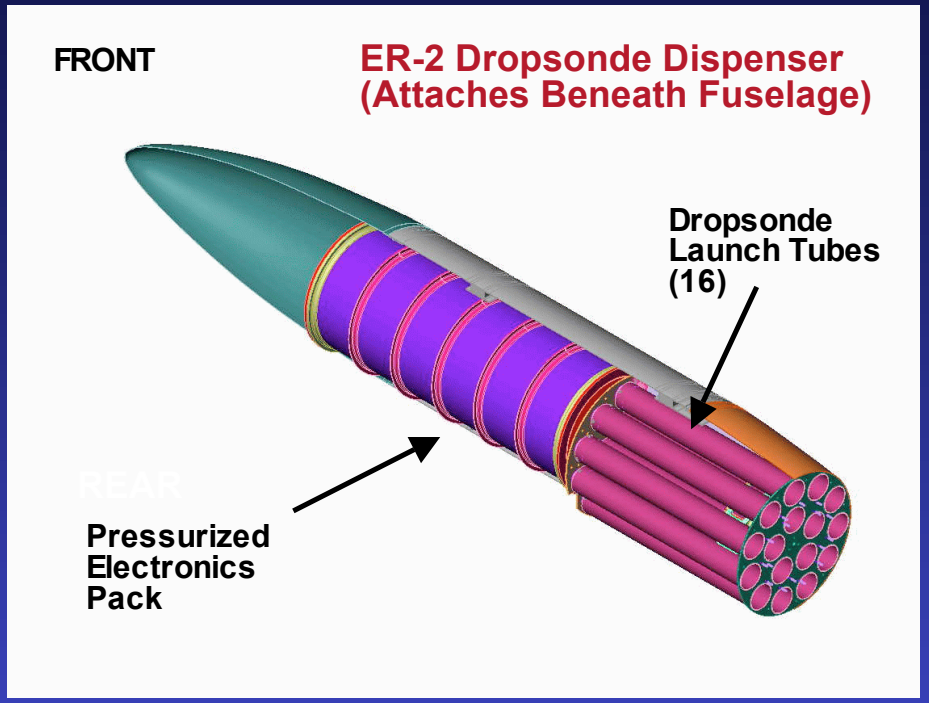





# Pioneering Science: ER-2 High Altitude Dropsonde (EHAD)

J. Halverson, J. Simpson, G. Heymsfield, H. Pierce, T. Hock, E. Ritchie, 2005, Warm core structure of Hurricane Erin diagnosed from high altitude dropsondes during CAMEX-4, *J. Atmos. Sci.*

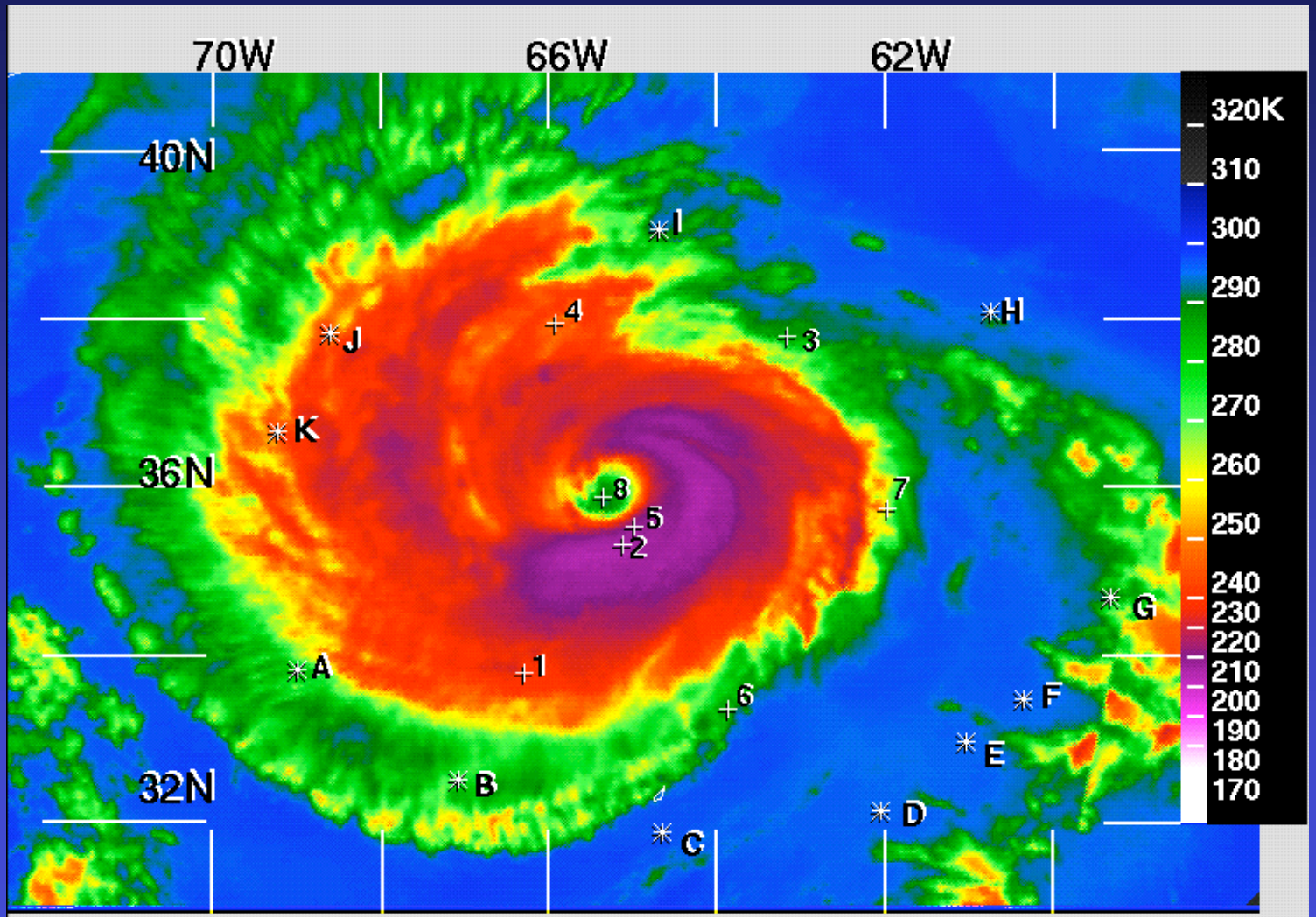





**First release into hurricane eye from 70,000' - September 10, 2001**

- 3D map of eye's thermal structure from 70,000' to ocean surface in great detail
- Relationship b/t warming in the eye and reduction in surface pressure
- Weakening of the inner core from top down > storm vulnerable to wind shear > redistribution of heavy rain (asymmetry)

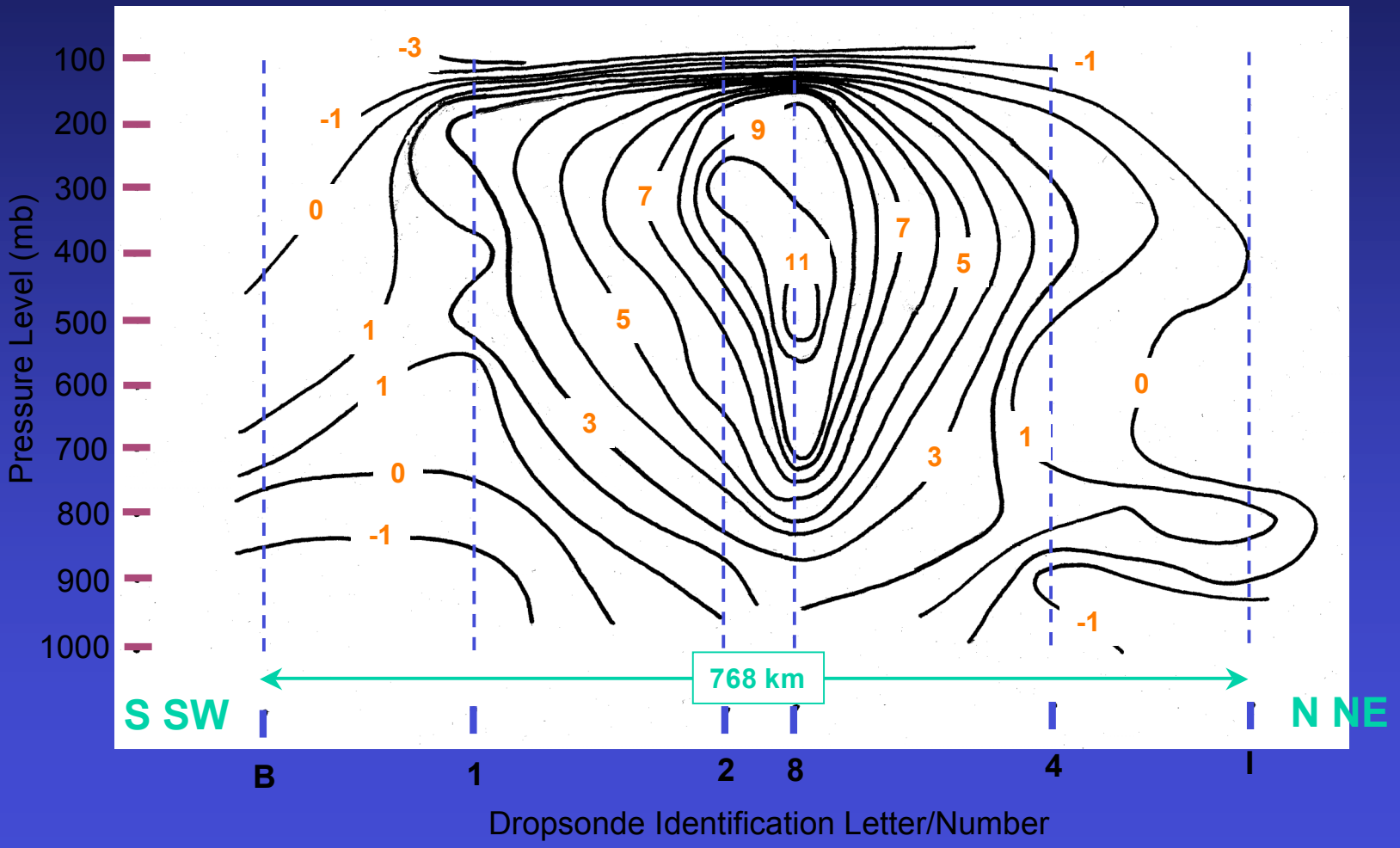
# Surveying the Core of Hurricane Erin



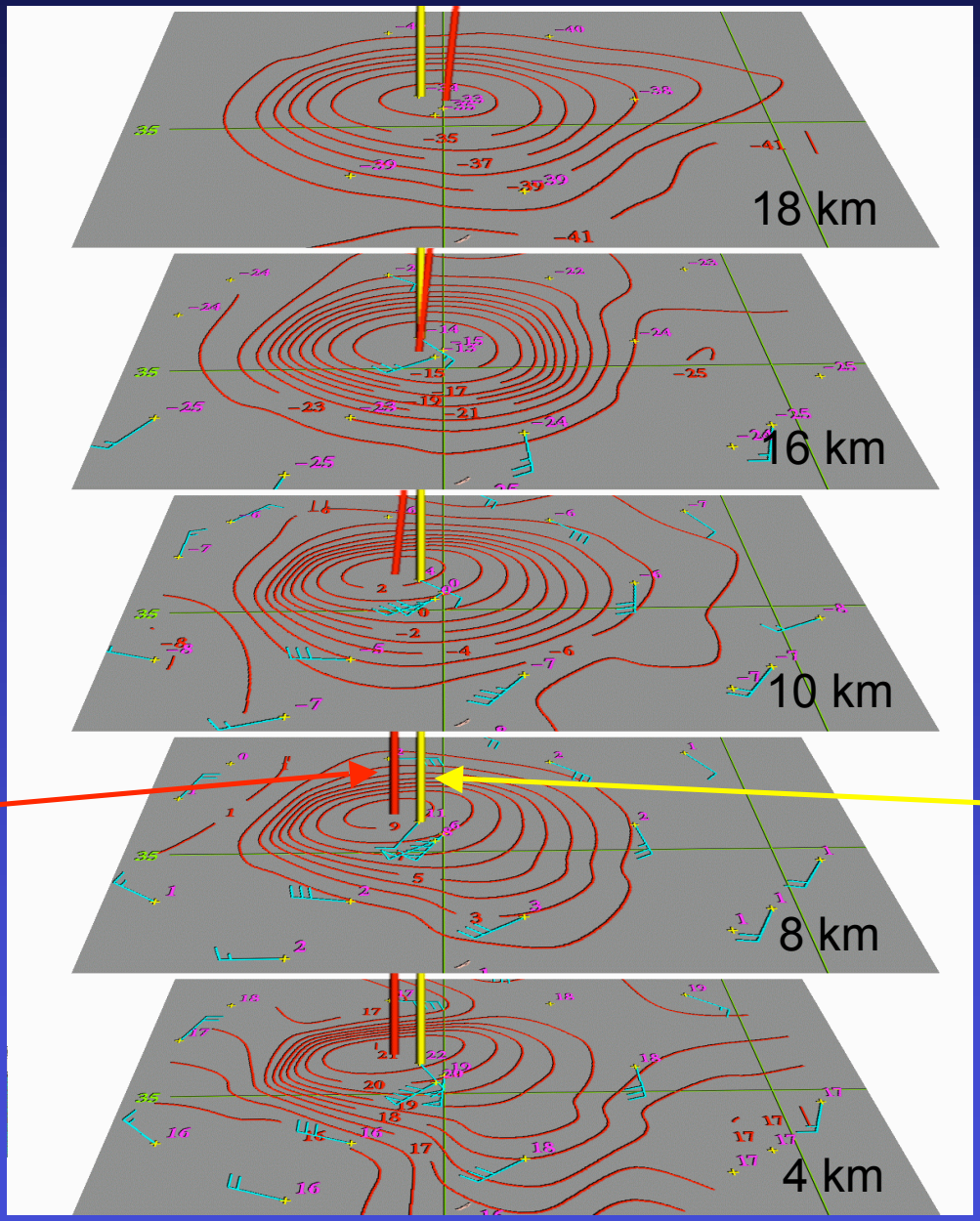

GOES IR Image of hurricane Erin at 1932 UTC. Positions of NASA DC8 (*) ER2 (+) dropsondes have been overlaid.

# Mapping The 3D Temperature in Erin's Core

J. Halverson, J. Simpson, G. Heymsfield, T. Hock, H. Pierce, L. Ritchie, 2005, *J. Atmos. Physics*

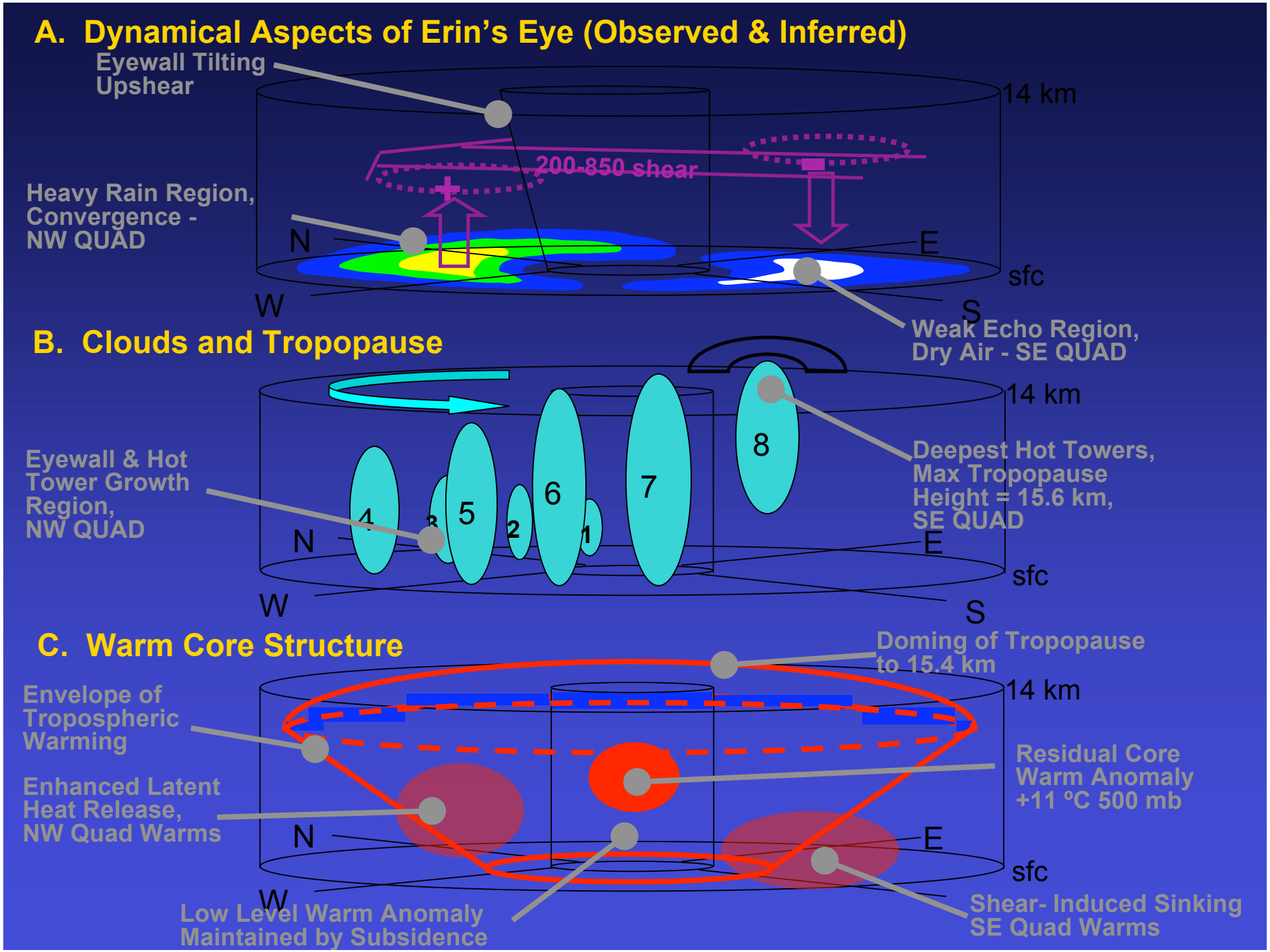


# 3D Structure of Erin's Eye




Axis of Asymmetric Heating

Center of Dynamic Vortex


A. Dynamical Aspects of Erin's Eye (Observed & Inferred)
Eyewall Tilting Upshear
14 km
200-850 shear
Heavy Rain Region, Convergence - NW QUAD
N
E
sfc
W
S
Weak Echo Region, Dry Air - SE QUAD
B. Clouds and Tropopause
14 km
Eyewall & Hot Tower Growth Region, NW QUAD
1
2
4
5
6
7
8
Deepest Hot Towers, Max Tropopause Height = 15.6 km, SE QUAD
N
E
sfc
W
S
C. Warm Core Structure
Doming of Tropopause to 15.4 km
14 km
Envelope of Tropospheric Warming
Residual Core Warm Anomaly +11 ºC 500 mb
Enhanced Latent Heat Release, NW Quad Warms
N
E
sfc
W
Low Level Warm Anomaly Maintained by Subsidence
Shear- Induced Sinking SE Quad Warms

# The Allure of Tropical Meteorology